Computer Modeling of Respiratory Protection

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NIST

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Outline

- Project goals and approach
- Exterior respirator leak – NIOSH project
- Interior flow model – Geometry setup
- Test problem
- Plans

Fire Fighter Respiratory Protection

- Respirators must protect against many hazards
  - Particulates, chemical and biological toxins
  - Lack a priori knowledge of threats
- Wide range of situations
  - Normal and high stress
  - Short duration: fire suppression
  - Long duration: salvage and search and rescue
- Issues
  - Leaks
  - Poor fit
  - Heavy breathing and coughing
  - Temporary removal

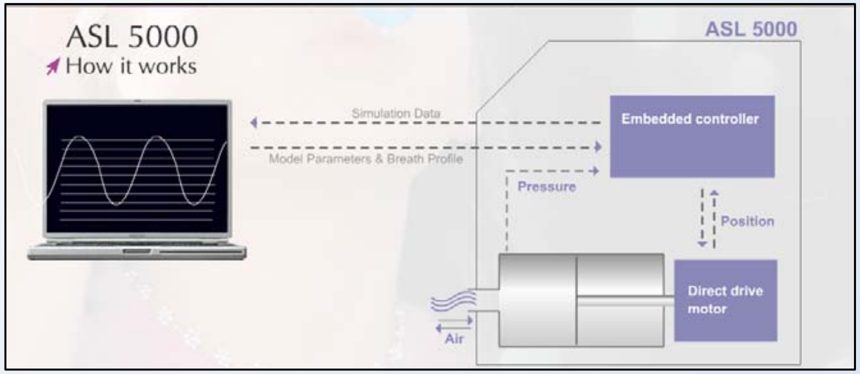
Objective

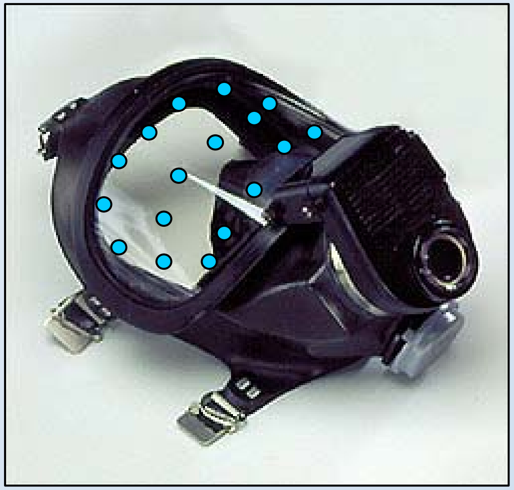
To improve respiratory protection of first responders by

- developing a modeling tool and experiments to characterize the flow within a fire fighter’s respirator mask and by
- predicting respiratory uptake of toxic gases and fine particulates from the environment in the presence of a leak.

Experimental Setup – Rodney Bryant

- Breathing simulator (on order)
- Instrument head form and mask to measure pressure field
- Additional measurements include
    - Aerosol concentration
    - Gas concentration
- Develop miniature optical aerosol sensor with NASA Glenn





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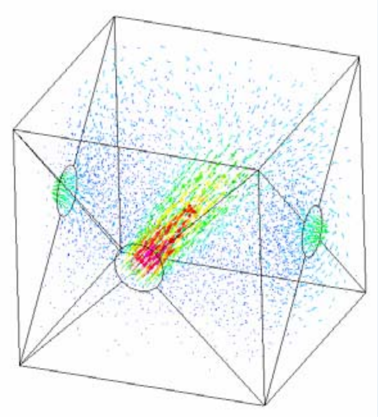
Computational Model



- Can test variety of situations
  - Breathing pattern
  - Leak geometries
  - External environments
- Visualization of results
  - Velocity
  - Pressure
  - Particle traces
  - Oxygen / fuel gas concentrations
- Complex geometry
  - Finite element or finite volume

NIOSH Project:
Closed Circuit, Self-Contained Breathing Apparatus

- Compressed air tanks contain a maximum 1 hour supply
- Longer durations may be necessary for emergency responders
  - Contaminated environments, including CBRN
  - Tunnels, mines, ships, high-rise buildings
- CC-SCBA (rebreather) enables up to 4 hour use
  - Recirculates exhaled gas
  - CO2 absorbed
  - Fresh oxygen added

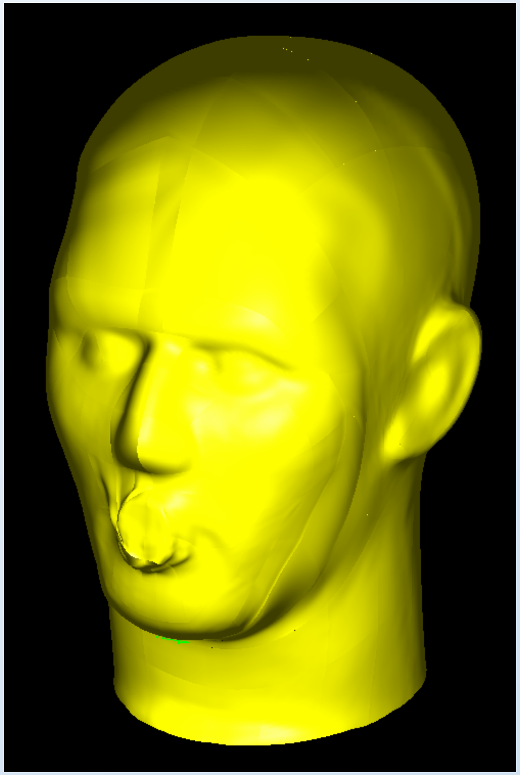
Firefighter concern: Since the supply tank contains pure oxygen, what happens if there is a respirator leak in a fire environment?

Head Geometry

3-D Scanner

3-D points

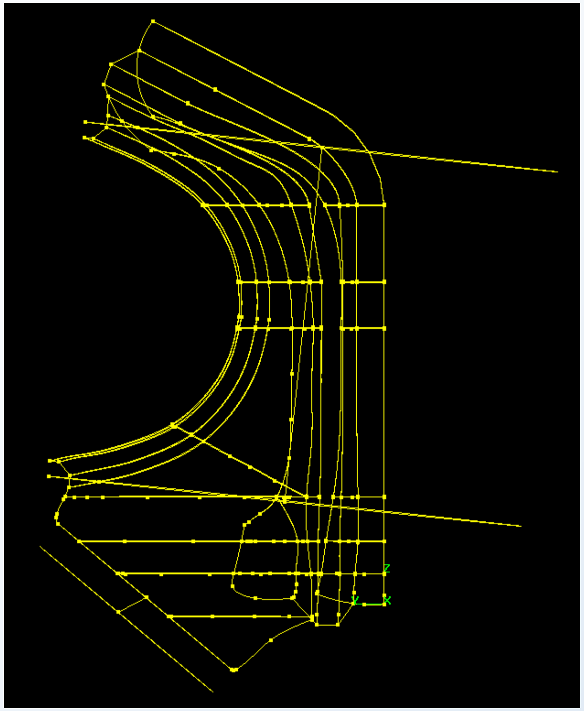
Smoothed, holes filled

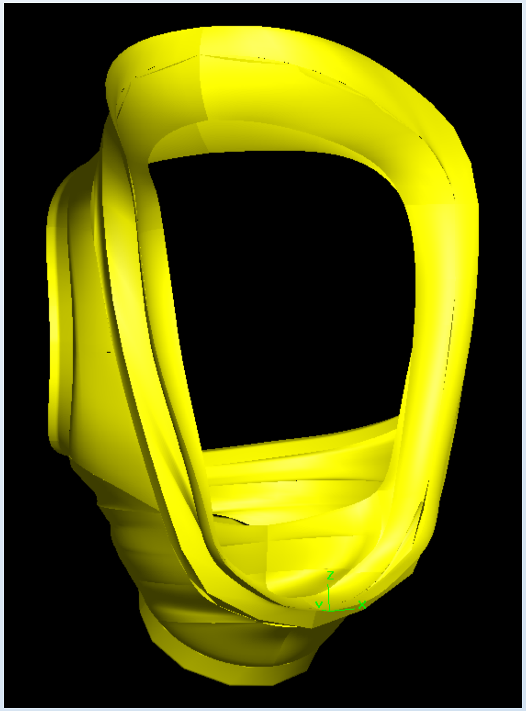


Clay removed

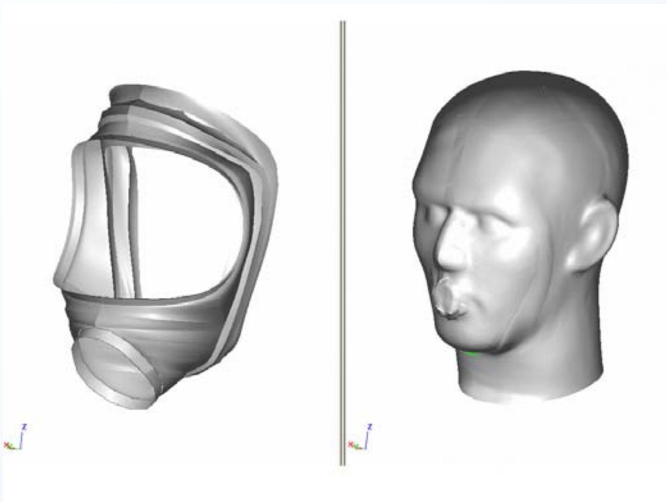
Mask Geometry

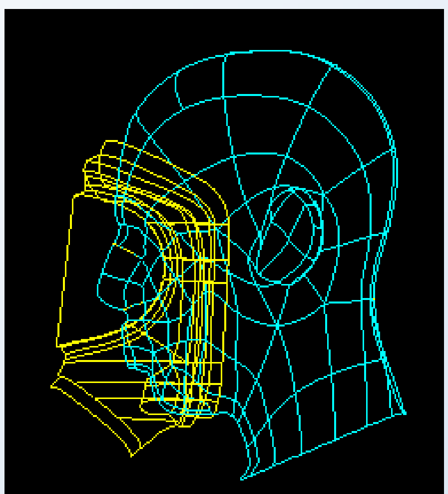
Mechanical Drawings

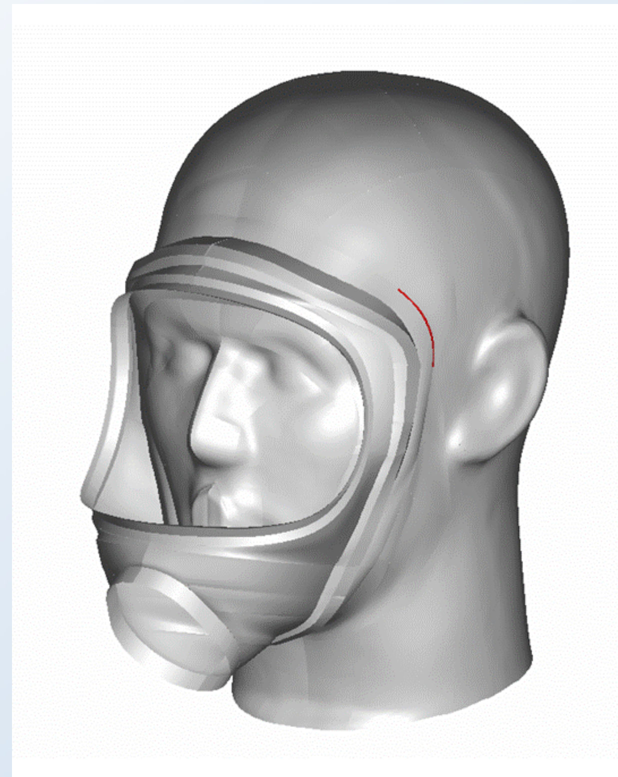




Head + Mask Combination

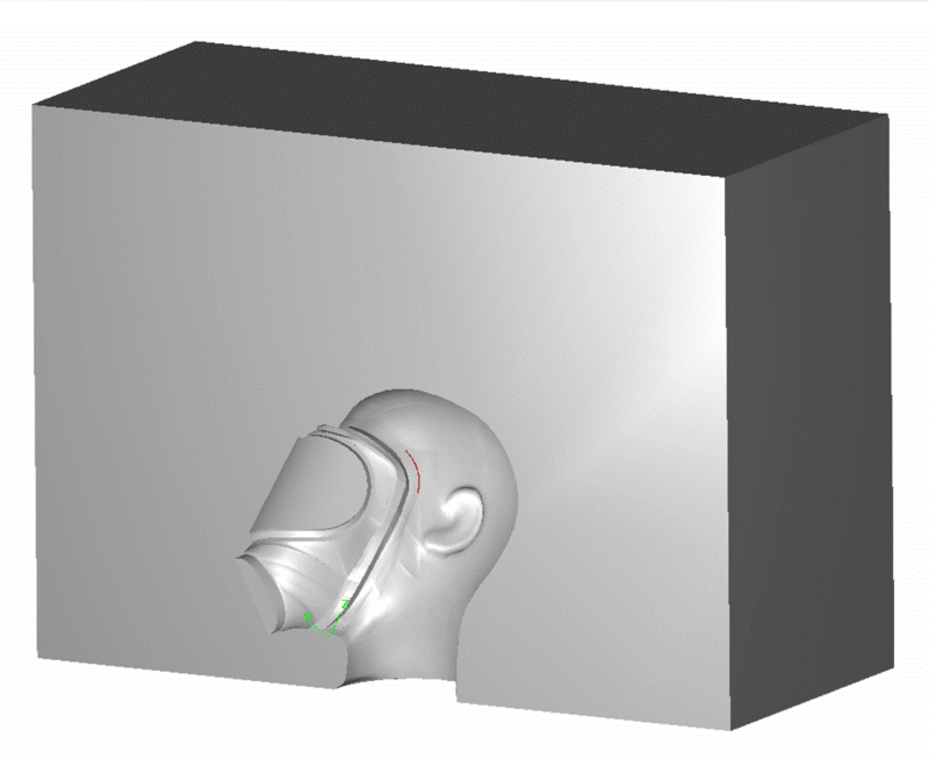




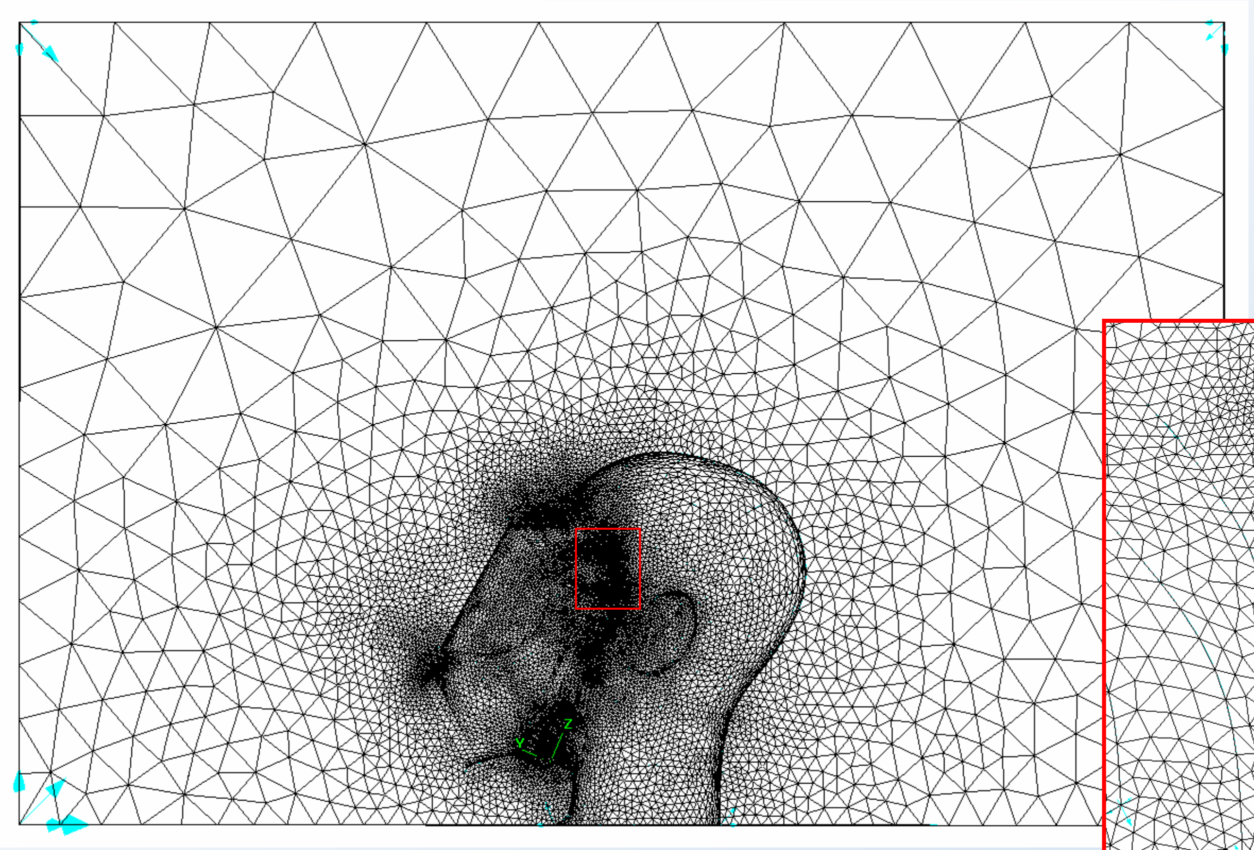


Problem Geometry

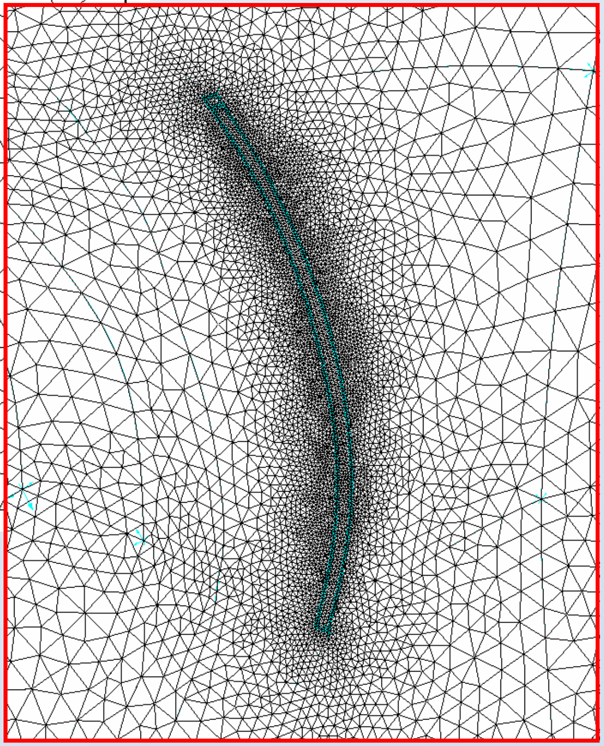
- Exterior to head + mask
- Symmetric – cut problem in half
- Define a leak region



Mesh – Refined where needed

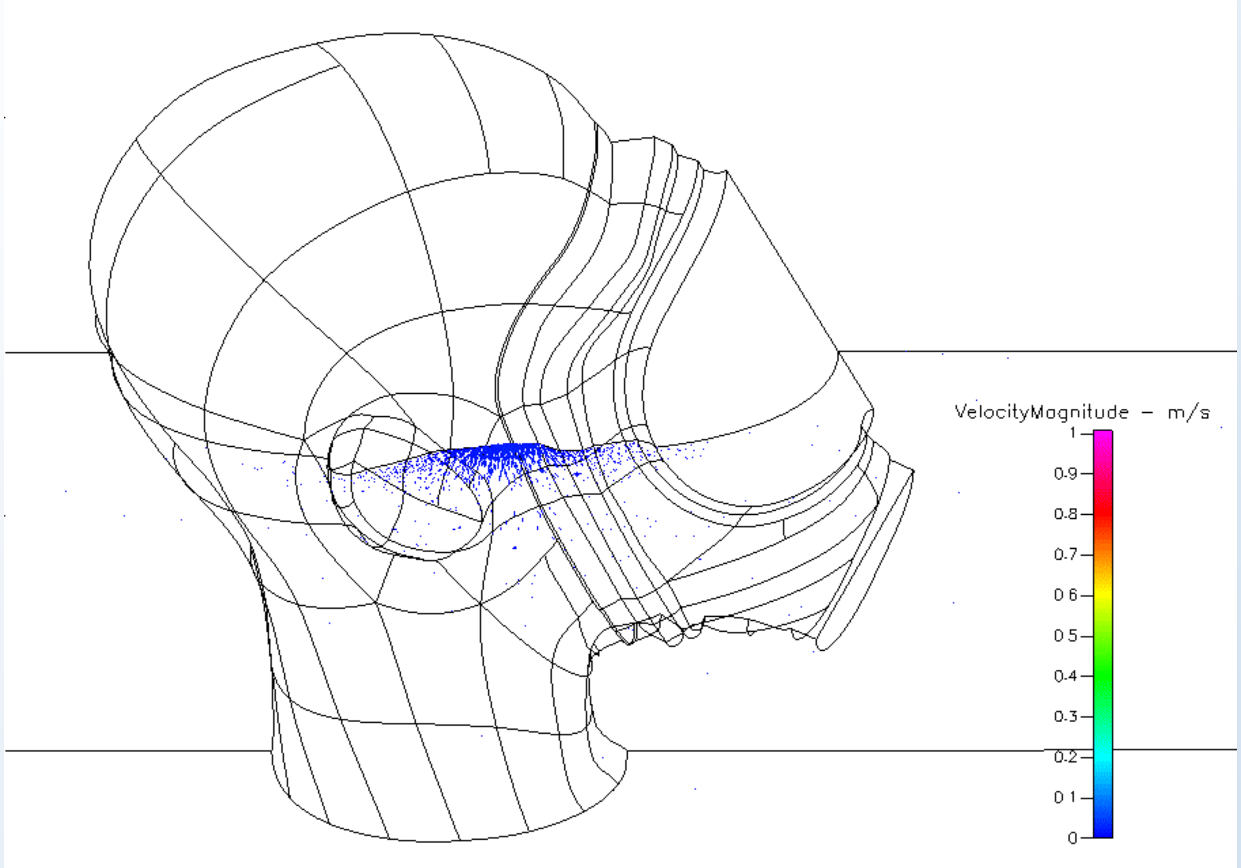


Leak



Mesh boundaries first, then interior
→ 465,000 cells

Velocities along Leak Length

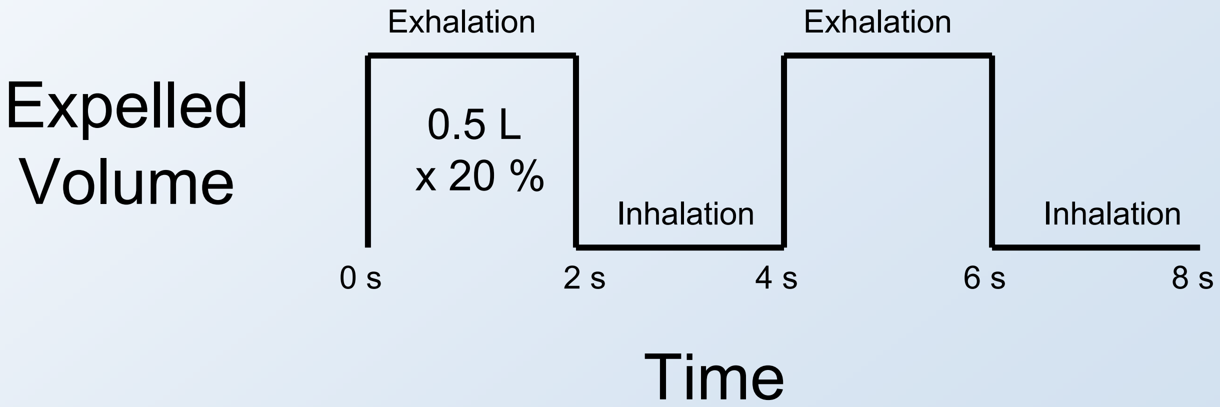


Normal Breathing Pattern

Assume

- 15 breaths per minute
- 0.5 L tidal volume
- 20 % lost through leak during exhalation
- Leak closes during inhalation
- Leak 1 mm wide x 44 mm long

  → Velocity ≈ 1 m/s at leak



Model Conditions

- For propane,

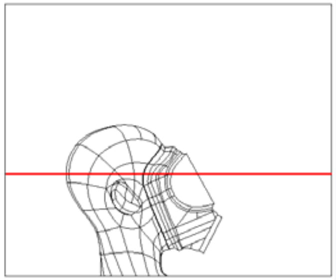
  Lower Flammable Limit (LFL) = 2.8 %
  Upper Flammable Limit (UFL) = 9.5 %

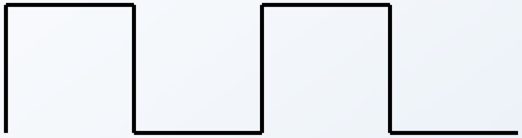
- Outside of these limits, will not burn

Worst Case Scenario

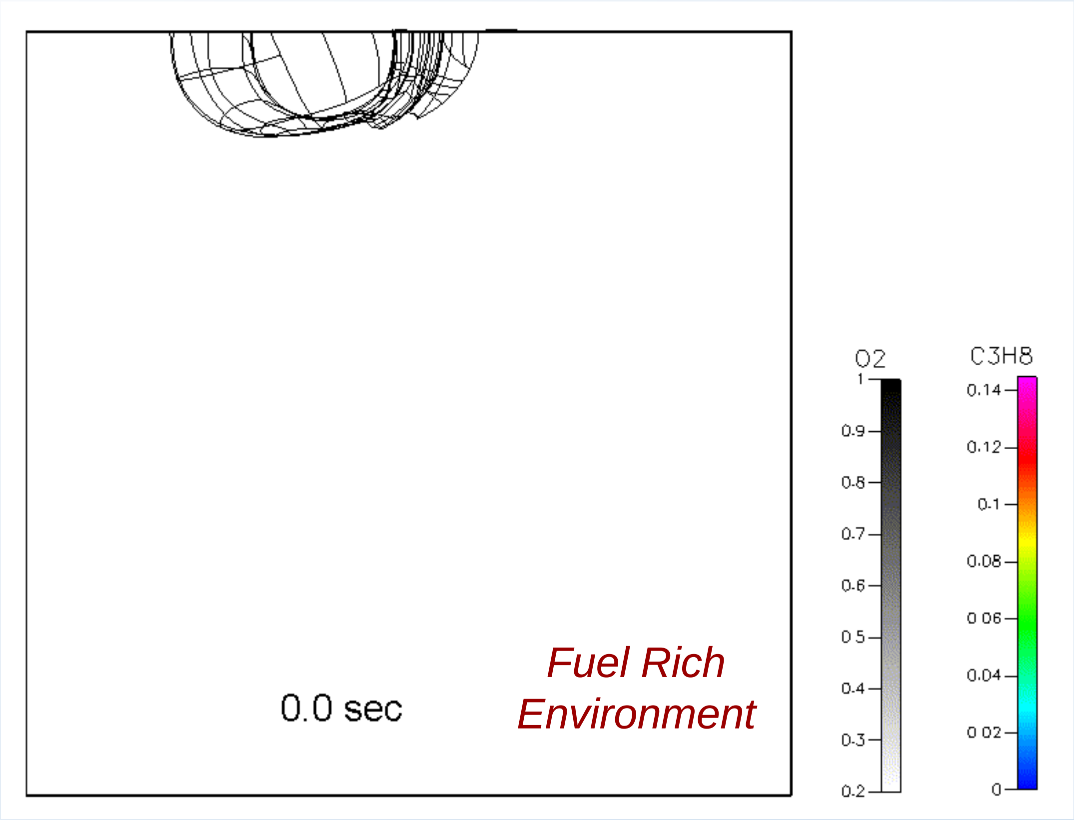
External Environment:	10 % Propane Gas (just above UFL = 9.5 %)
Exhaled from Leak:	100 % Oxygen

Oxygen Concentration / Propane LFL and UFL





- 10% Propane Gas
- 100% Oxygen Leak (during exhalation only)
- Normal breathing



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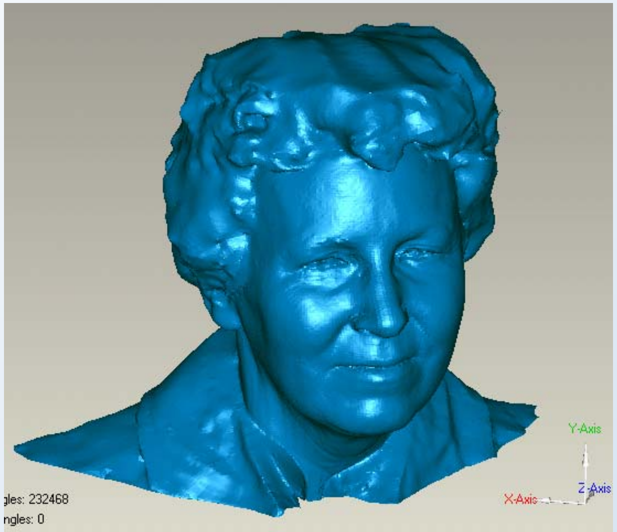
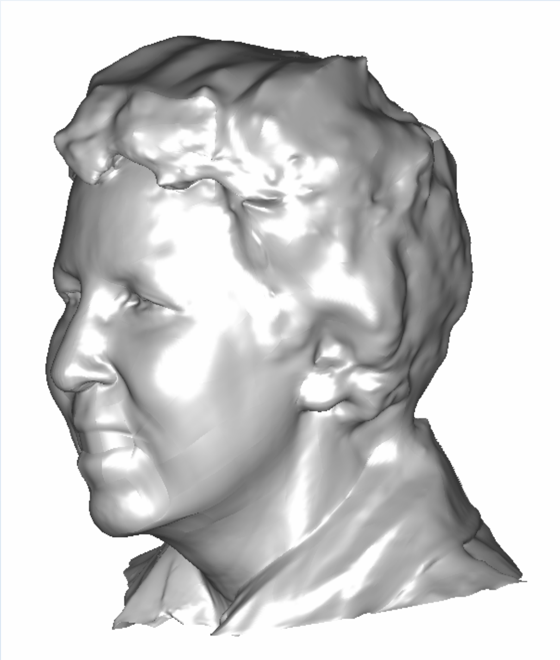
Head Geometry

3-D Scanner

3-D points



Smoothed, holes filled



Mouth open

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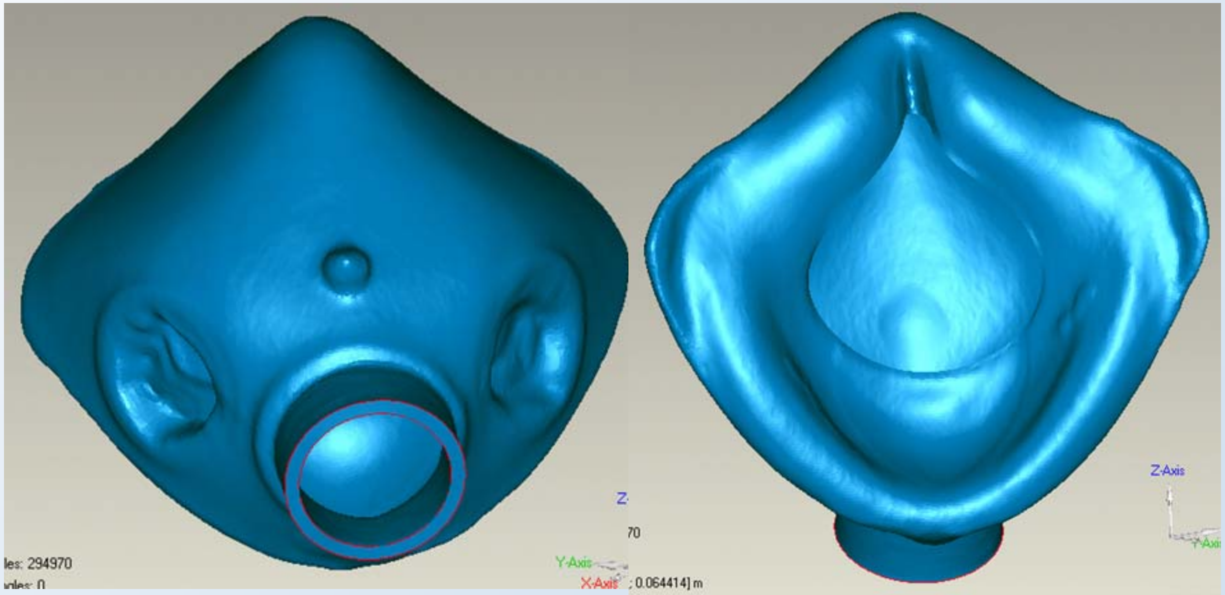
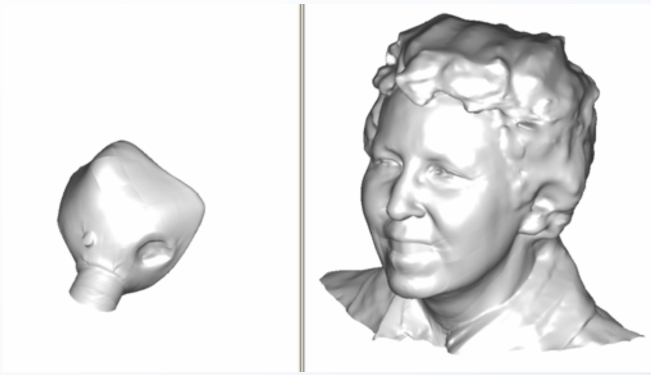
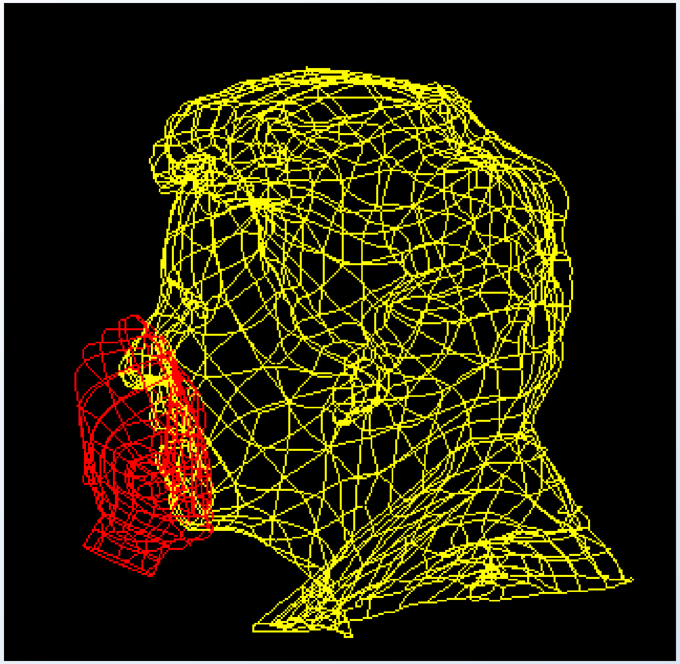
Mask geometry

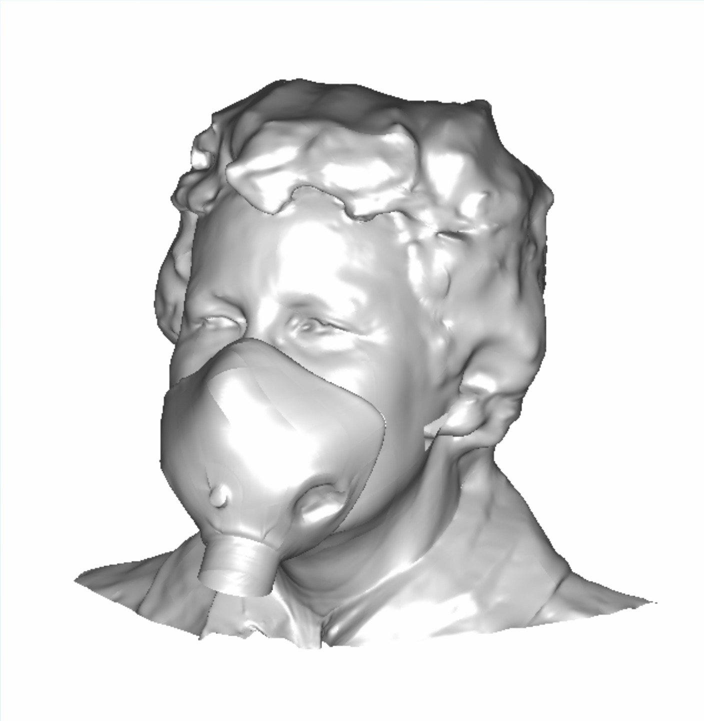
3-D Scanner



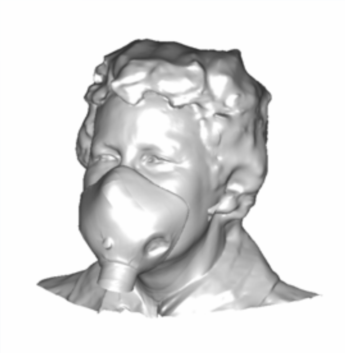
Head + Mask Combination





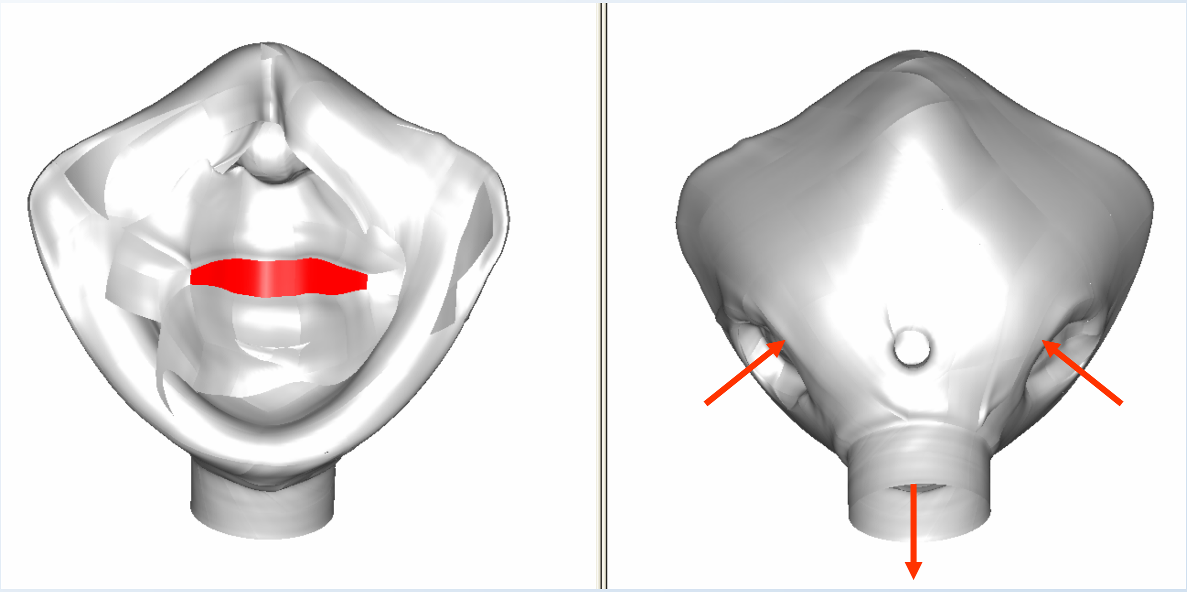


Geometry for Interior Flow Model

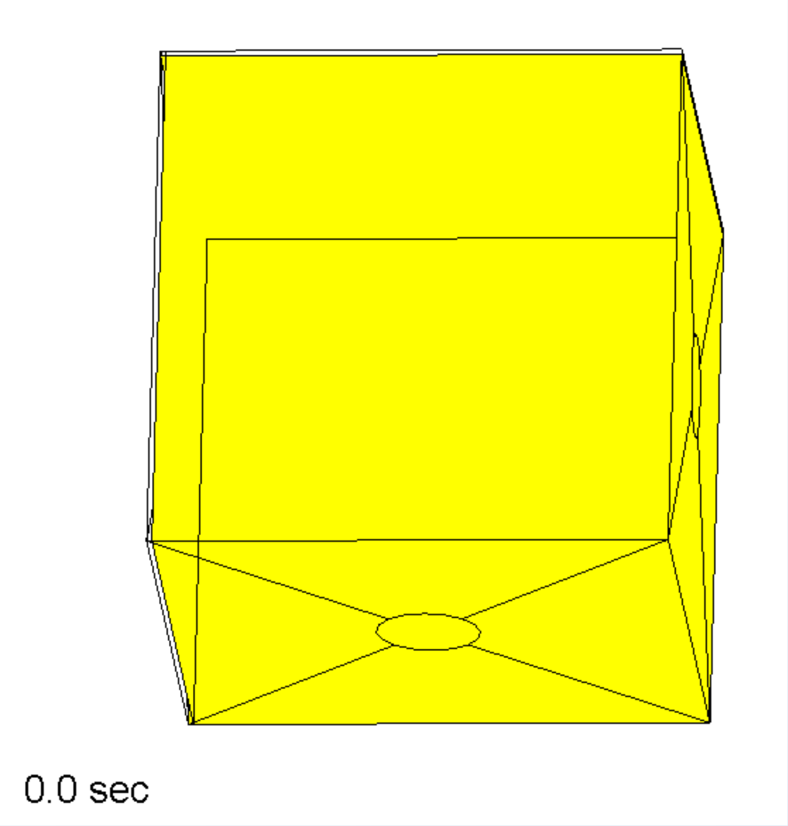


To be done:

- Connect head to mask
- Make finite element grid
- Define boundary conditions
- Run problem



Rectangular Test Model - Results



Plans

- Flow of gas within respirator
- Inhalation and deposition patterns for particles with mass
- Compare with experiment
- Vary:
  - Mask and head geometries
  - Leak conditions
  - Breathing rates
- Flexible skin and polymer
- Sneeze

Acknowledgments

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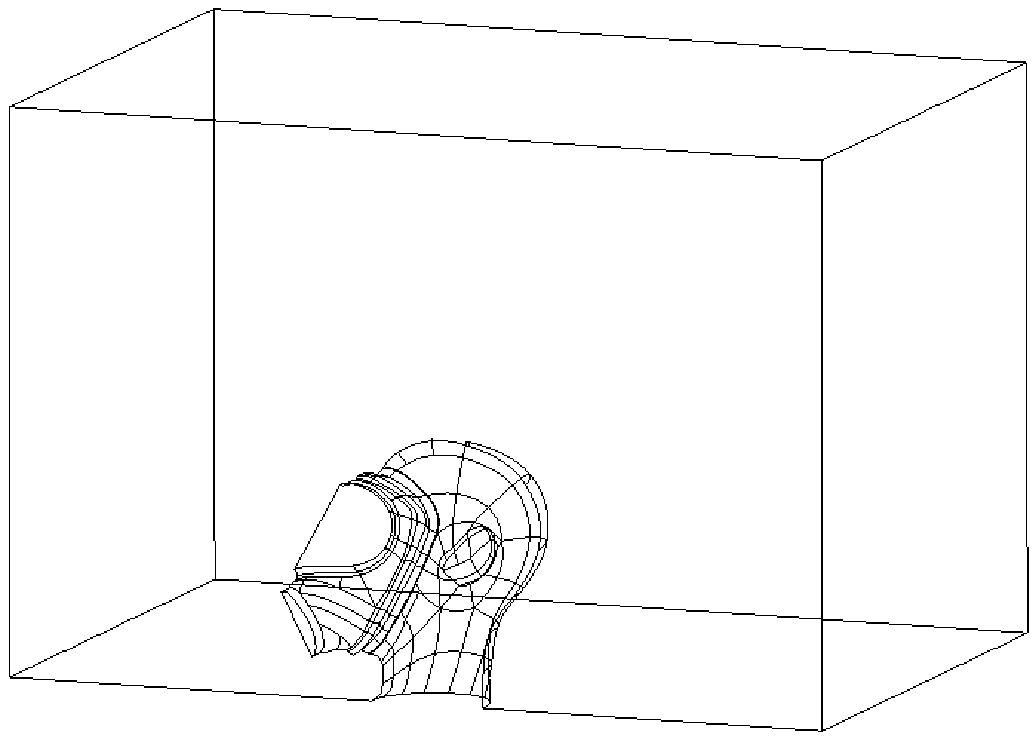
3-D Geometry



Rectangular Test Model - Results